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Evaluation of a Dust Control for a Small Slab-Riding Dowel Drill for Concrete Pavement

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Abstract

Purpose—To assess the effectiveness of local exhaust ventilation to control respirable crystalline silica exposures to acceptable levels during concrete dowel drilling.

Approach—Personal breathing zone samples for respirable dust and crystalline silica were collected while laborers drilled holes 3.5 cm diameter by 36 cm deep in a concrete slab using a single-drill slab-riding dowel drill equipped with local exhaust ventilation. Data were collected on air flow, weather, and productivity.

Results—All respirable dust samples were below the 90 μg detection limit which, when combined with the largest sample volume, resulted in a minimum detectable concentration of 0.31 mg m^{-3} . This occurred in a 32-min sample collected when 27 holes were drilled. Quartz was only detected in one air sample; 0.09 mg m^{-3} of quartz was found on an 8-min sample collected during a drill maintenance task. The minimum detectable concentration for quartz in personal air samples collected while drilling was performed was 0.02 mg m^{-3} . The average number of holes drilled during each drilling sample was 23. Over the course of the 2-day study, air flow measured at the dust collector decreased from 2.2 to 1.7 $\text{m}^3 \text{s}^{-1}$.

Conclusions—The dust control performed well under the conditions of this test. The initial duct velocity with a clean filter was sufficient to prevent settling, but gradually fell below the recommended value to prevent dust from settling in the duct. The practice of raising the drill between each hole may have prevented the dust from settling in the duct. A slightly higher flow rate and an improved duct design would prevent settling without regard to the position of the drill.

Keywords

concrete; drilling; respirable; silica; ventilation

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INTRODUCTION

Horizontal drilling of concrete pavement to insert steel dowels is performed in highway and runway construction. Steel dowels transfer loads between adjacent concrete pavement slabs (Park et al., 2008). Dowel drilling without dust controls can expose workers to respirable silica above applicable exposure limits, endangering their health (Linch, 2002; Valiante et al., 2004). Valiante et al. (2004) reported that dowel drilling respirable crystalline silica exposures ranged from 0.05 to 0.16 mg m⁻³, 8-h time-weighted average (TWA). Linch (2002) reported 8-h TWA quartz exposures for operators and laborers using boom-mounted three-gang dowel drilling machines. The operators' 8-h TWA exposures ranged from less than the minimally detectable concentration of 0.029 to 0.11 mg m⁻³, with a geometric mean respirable crystalline silica exposure of 0.037 mg m⁻³ for eight samples. The laborers' 8-h TWA respirable crystalline silica exposures ranged from 0.12 to 1.3 mg m⁻³, with a geometric mean of 0.24 mg m⁻³ for eight samples. The NIOSH Recommended Exposure Limit for respirable crystalline silica is 0.05 mg m⁻³ as a TWA for up to a 10-h workday during a 40-hr workweek (NIOSH, 2002). The proposed OSHA permissible exposure limit is 0.05 mg m⁻³, as an 8-h TWA (OSHA, 2013).

Typical dowel drilling machines have one or more drills held parallel in a frame that aligns the drills and prevents the bits from wandering (FHWA, 2015). The dowel drilling machine may be manually positioned, self-propelled or boom mounted, and may ride on the slab or on the grade (FHWA, 2015). After drilling to a typical depth of 23 cm, the anchoring material is placed, and the dowel is installed. The diameter of the hole is determined by the dowel diameter and whether cement-based grout or an epoxy compound is used to anchor the dowels (FHWA, 2015). Compressed air may be used to clean the hole.

Dowel drilling was performed by two instructors at a Laborers training center. They took turns operating a new, single-drill slab-riding dowel drill (model A1C, Minnick Manufacturing Company, Inc., Mansfield, OH, USA). The drill was equipped with the manufacturer's dust collection system.

The drill used H-thread steels and bits to drill 3.5 cm diameter horizontal holes 36 cm into the side of a new 4000 psi air-entrained concrete slab, 9.1 m long by 1.5 m wide by 23 cm high. The bit shank was surrounded by a hood attached to 5 cm diameter corrugated flexible hose (the interior was also corrugated), attached to a dust collector at the back of the dowel drill; a pneumatic eductor on top of the dust collector (Fig. 1) pulled the control air through a pleated filter cartridge with a minimum efficiency reporting value (MERV) of 13 (P148646-016-340, Donaldson Company, Inc., Bloomington, MN, USA). During operation, captured dust built up on the filter cartridge to create a dust cake. As the dust cake accumulates on the filter, filtration efficiency increases but so does the air flow resistance (ACGIH, 2010). The drill operator periodically cleaned the filter by triggering a reverse pulse jet. At the bottom of the dust collector, a plastic bucket collected accumulated dust. This bucket was dumped when the laborer noticed visible dust around the surface of the drill. The laborer also removed and manually cleaned the filter at that time.

The work cycle included positioning the drill, drilling the hole, and repositioning the drill for the next hole. Maintenance included manually cleaning the filter by rolling and tapping it on the ground every time the plastic dust-collection bucket was emptied.

The study was approved by the NIOSH Human Subjects Review Board. The protocol required the use of dust controls whenever they were present. The laborers wore N-95 filtering-facepiece respirators (model 8511, 3M Occupational Health and Environmental Safety, St. Paul, MN, USA), hardhats, safety glasses, ear plugs, work gloves, and work boots.

We previously assessed personal respirable dust and respirable crystalline silica exposures of workers operating dowel drilling machines with dust controls in place at construction sites (Echt et al., 2011; 2012). However, it was difficult to control the work practices of employees using the drills on those sites. It was also hard to control equipment maintenance and other issues not related to dust-capture system performance. The purpose of this investigation was to use the low-pressure environment of a training center to control those factors and measure exposures with the dust control working as designed, using a drill and dust control delivered from the factory with the manufacturer instructing the operator in its correct use.

MATERIALS AND METHODS

A respirable particulate sample was collected while the instructor drilled holes. When it was time to empty the dust collection bucket, both the drilling and its associated air sampling was stopped. A separate air sample was collected while the bucket was emptied. That sampling was stopped when the bucket was reinstalled. The drill was repositioned for a new hole then the drilling and a new air sample began. Nine samples were collected during drilling, including one while the bit was changed. Seven samples were collected while the bucket was emptied, including one when the drill was turned and three when the filter was cleaned. Full shift samples were not collected.

Personal breathing zone samples were collected at a flow rate of 9 L min^{-1} using pumps (Model LP-12, A.P Buck, Inc., Orlando, FL, USA) calibrated before and after each day's use. A back belt with suspenders was used to support the pump and sampling train. The pump was clipped to the back belt and connected via Tygon[®] tubing to the outlet of a three-piece conductive cassette (No. 225–8497, SKC, Inc., Eighty Four, PA, USA) containing a pre-weighed, 47-mm diameter, $5 \mu\text{m}$ pore-size polyvinyl chloride (PVC) filter (No. 66468, Pall Corp., Ann Arbor, MI, USA) and a backup pad (No. 225–2903 SKC, Inc., Eighty Four, PA, USA), and sealed with a shrink band. The front section of the cassette was removed and the portion of the cassette holding the filter was attached to the top of the cyclone (model GK 4.162, Mesa Labs, Inc., Butler, NJ, USA). The cyclone was clipped to the suspender strap within the worker's breathing zone. That cyclone has a 50% cut point of $3.91 \mu\text{m}$ at 9 L min^{-1} (HSL, 2012). Gravimetric analysis of the respirable dust sample was conducted using NIOSH Method 0600 (Schlecht et al., 1998). The filters were allowed to equilibrate for at least 2 h before weighing. Each filter was passed over a static neutralizer in front of the balance (model AT201, Mettler-Toledo, LLC, Columbus, OH, USA) and weighed. The limit

of detection (LOD) was $90 \mu\text{g sample}^{-1}$. The limit of quantitation (LOQ) was $300 \mu\text{g sample}^{-1}$.

Crystalline silica analysis was performed using NIOSH Method 7500 (Schlecht et al., 2003) with modifications. Each filter was transferred to a 15-ml vial and dissolved in 10 ml of tetrahydrofuran (THF), vortexed, and placed in an ultrasonic bath for 10 min. A silver-membrane filter was placed in the vacuum filtration unit and 2 ml of THF was placed onto it. The sample suspension was vortexed and immediately added onto the silver-membrane filter. The vial was rinsed three times with 2 ml THF. Each rinse was added to the sample on the silver-membrane filter. Vacuum deposited the sample suspension onto the filter. The silver-membrane filter was analyzed by X-ray diffraction. The LOD for quartz was $6 \mu\text{g sample}^{-1}$. The LOQ was $20 \mu\text{g sample}^{-1}$.

The maximum air sample volume collected was 292 L; this volume provided for a minimum detectable quartz concentration of 0.02 mg m^{-3} in a 32-min sample. The minimum quantifiable quartz concentration was 0.068 mg m^{-3} .

Dust collector air flow was measured using a mass flow meter with a range of $0\text{--}2.83 \text{ m}^3 \text{ min}^{-1}$ (Model 730-N5-1 Sierra Instruments, Inc., Monterey, CA, USA). A Sierra Instruments, Inc. Model 954 Flo-Box was used to read the signal from the meter. A coupling (Model RC 50, American Valve, Greensboro, NC, USA) was used to attach a 30-cm long piece of Schedule 40 plastic pipe to the dust collector inlet. A threaded adapter connected the pipe to the outlet of the mass flow meter. Another threaded adapter was connected to the inlet of the mass flow meter. This adaptor was attached to a 27-cm long piece of pipe. The other end of that pipe was open to the atmosphere. While this measurement technique did not measure the actual flow through the hood and duct during drilling, it was a necessary alternative since the abrasive concrete dust would have destroyed the air flow sensor.

A weather station recorded data every 10 min (Kestrel 4500, Nielsen-Kellerman, Boothwyn, PA, USA). It was mounted on a tripod 1.5 m high; about breathing zone height (NIOSH, 2010). Average wind direction was calculated using published methods (EPA, 2000).

Productivity was measured by counting the holes drilled during each sampling period.

RESULTS

Table 1 presents air sampling results. No respirable dust was detected (MDC 0.31 mg m^{-3}). Quartz was detected in one air sample, when a laborer emptied the bucket, struck the dust collector to dislodge dust, and triggered the reverse pulse. The remaining results were less than the minimum detectable concentration (0.02 mg m^{-3}). One air sample was lost due to a laboratory error.

On day 1, the average wind speed was 1.1 m s^{-1} , the average temperature was 28°C , and the average relative humidity was 56%. For day 2, nearby airport data were used due to a hard drive failure and the average wind speed was 2.3 m s^{-1} , the average temperature was 25°C , and the average relative humidity was 89%.

From 9 to 29 holes were drilled per sample (including 28 holes drilled during the lost sample), with an average of 23 holes drilled per sample and 178 total holes drilled. The 9-hole sample reflects a period when a few holes were drilled and the bit was changed. Most drilling sample periods ended when the operator determined the bucket was full.

The first day, the airflow through the control was $2.2 \text{ m}^3 \text{ min}^{-1}$ measured with a clean filter, and $1.9 \text{ m}^3 \text{ min}^{-1}$ after drilling. The second day, the air flow was $1.7 \text{ m}^3 \text{ min}^{-1}$ measured before and $1.8 \text{ m}^3 \text{ min}^{-1}$ after the filter was removed for cleaning. The calculated velocities based on the air flow and the duct area under the conditions above were 18, 16, 14, and 14 m s^{-1} , respectively.

DISCUSSION

While the control was effective, air flow dropped as the filter was loaded, and recovered somewhat when it was cleaned. The low dust exposures were likely the result of the control, rather than the wind at the site. The industrial ventilation manual recommends a transport velocity of $18\text{--}20 \text{ m s}^{-1}$ for 'average industrial dust' (e.g., granite or limestone dust, brick cuttings, silica flour) (ACGIH, 2010). The initial duct velocity with a clean filter was sufficient, but gradually fell below the recommended value. In this site visit, the practice of raising the drill between each hole may have helped dislodge settled dust in the duct, though it may have slowed the work rate.

For filter cleaning frequency, instead of relying upon hole counts or driller observations, a static pressure gauge across the filter could give the driller information on when to clean the filter. The filter manufacturer could supply the recommended performance values. Alternatively, a hood static pressure gauge would indicate when the control air flow rate was falling. The flow rate and hood static pressure performance curve would have to be determined experimentally.

CONCLUSIONS

The dust control performed well, but the performance of the system could be improved to maintain the air flow and transport velocity throughout filter loading. Research has demonstrated that certain types of dust collectors used in the construction industry can do this effectively (Heitbrink and Santalla-Elias, 2009). This study also highlights the utility of a high-flow size-selective sampler for determining short duration task-based respirable quartz exposures in construction.

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Figure 1.
Laborer operating dowel drill.

Table 1

Air Sampling Results

Duration (min)	Volume (L)	Dust LOD (ug sample ⁻¹)	Quartz LOD (ug sample ⁻¹)	Respirable Dust (mg m ⁻³)	Quartz (mg m ⁻³)	Activity	Holes Drilled
18	164	90	6	<0.55	<0.04	drill holes	13
32	292	90	6	<0.31	<0.02	drill holes	27
28	256	90	6	<0.35	<0.02	drill holes ^a	27
17	155	90	6	<0.58	<0.04	drill holes ^b	9
17	155	90	6	<0.58	<0.04	drill holes	19
20	183	90	6	<0.49	<0.03	drill holes	26
32	284	90	6	<0.32	<0.02	drill holes	29
24	213	90	6	<0.42	<0.03	drill holes	28
3	27	90	6	<3.3	<0.2	empty bucket	
8	73	90	6	<1.2	0.09	empty bucket ^c	
2	18	90	6	<4.9	<0.3	empty bucket	
6	55	90	6	<1.6	<0.1	empty bucket ^d	
3	27	90	6	<3.3	<0.2	empty bucket	
9	80	90	6	<1.1	<0.08	empty bucket ^e	
9	80	90	6	<1.1	<0.08	empty bucket ^f	

^aThe laborer raised the drill after drilling each hole beginning with the 24th hole during this sample.

^bThe laborer stopped drilling after nine holes to change the bit.

^cThe laborer dumped the bucket, cleaned the filter, banged on the side of the dust collector, and used the reverse pulse feature.

^dThe sampled laborer removed the bucket, but the other laborer dumped it; they shared the task of cleaning the filter.

^eThe drill was turned during this sampling period.

^fThe laborer enclosed the filter in a plastic bag while he cleaned it.